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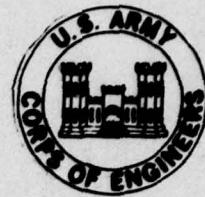
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ENGINEERING ASPECTS OF AN EXPERIMENTAL SYSTEM FOR LAND RENOVATION OF SECONDARY EFFLUENT

James R. Nylund, R.E. Larson, C.E. Clapp, D.R. Linden and W.E. Larson

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A research system was designed and installed at the Apple Valley Wastewater Treatment Plant, two miles south of Rosemount, Minnesota, to develop agricultural management practices for removal of nitrogen from municipal wastewater effluent. A solid set irrigation system was designed and installed to apply wastewater effluent to 12 test blocks, each measuring 60x150 ft. A perforated plastic drainage tile was placed lengthwise in each block at a depth equivalent to the normal water table level and opening at one end of the block.		

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20. Abstract (cont'd)

CONT

→ into a sampling station. Six blocks were planted to corn and six planted to eight species of forages. The effluent was applied at rates up to 15 ft/yr. This report presents the engineering considerations in the design of a solid set irrigation system and drain tile and monitoring system for evaluating the influence of the effluent application and agronomic practices on drainage waters.



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PREFACE

This report was prepared by James R. Nylund, R.E. Larson, C.E. Clapp, D.R. Linden and W.E. Larson, of the Agricultural Research Service, University of Minnesota, for the U.S. Army Cold Regions Research and Engineering Laboratory.

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These conversion factors include all the significant digits given in the conversion tables in the *ASTM Metric Practice Guide* (E 380), which has been approved for use by the Department of Defense. Converted values should be rounded to have the same precision as the original (see E 380).

<i>Multiply</i>	<i>By</i>	<i>To obtain</i>
inch	0.02540 [*]	meter
foot	0.3048 [*]	meter
mile (statute)	1609.3	meter
inch ³	0.00001638706	meter ³
acre	4046.873	meter ²
gal./minute	0.00006309020	meter ³ /second
pound	0.4535924	kilogram
pound force/in. ²	6894.757	pascal
quart	0.001101221	meter ³

^{*}Exact

ENGINEERING ASPECTS OF AN EXPERIMENTAL SYSTEM FOR LAND RENOVATION OF SECONDARY EFFLUENT

INTRODUCTION

The disposal of the products of wastewater treatment plants by land application has become increasingly popular as a means of meeting stringent water quality standards. For the past 4 years at the University of Minnesota, the U.S. Department of Agriculture, Science and Education Administration, in cooperation with the U.S. Army Corps of Engineers and the Metropolitan Waste Control Commission, has been experimenting with a system of effluent treatment using soil filtration and plant nutrient uptake as primary renovating agents. The Apple Valley experimental site, although not designed for full-scale high-volume wastewater treatment, nevertheless posed similar design considerations for effluent applications, soil drainage, and water-quality monitoring. This report will consider details of the design, operation, and maintenance of the system.

The Apple Valley site consists of 3 acres, 2 miles south of Rosemount, Minnesota, adjacent to the Apple Valley wastewater treatment plant. The land is open and nearly flat with 2 ft of a silt loam top soil and the water table about 6 ft below the soil surface. For experimental reasons, the area was divided into 12 rectangular 60- x 150-ft blocks (see Fig. 1), each of which was irrigated and drained separately. Corn was planted on six of the blocks and forage grasses on the other six. This made it possible to have two replications of three effluent application treatments (no effluent, low effluent, and high effluent) for each crop.

An irrigation system (Fig. 1, solid line) was designed to deliver either fresh water or secondary effluent to all or any one of the twelve blocks, as well as eight 40- x 40-ft plots of an auxiliary study added 1 year after the initial project started.

Perforated tile drains were installed (dashed lines) down the center of each block and between each block. These were connected to a solid drain line which ran to a common sump and lift pump where the water was discharged to a nearby stream.

I. Design

A. Irrigation system

Sewage is aerobically digested at the Apple Valley treatment plant and sludge is separated, filtered, chlorinated, and expelled to a nearby stream. The separated sludge is normally hauled by tank

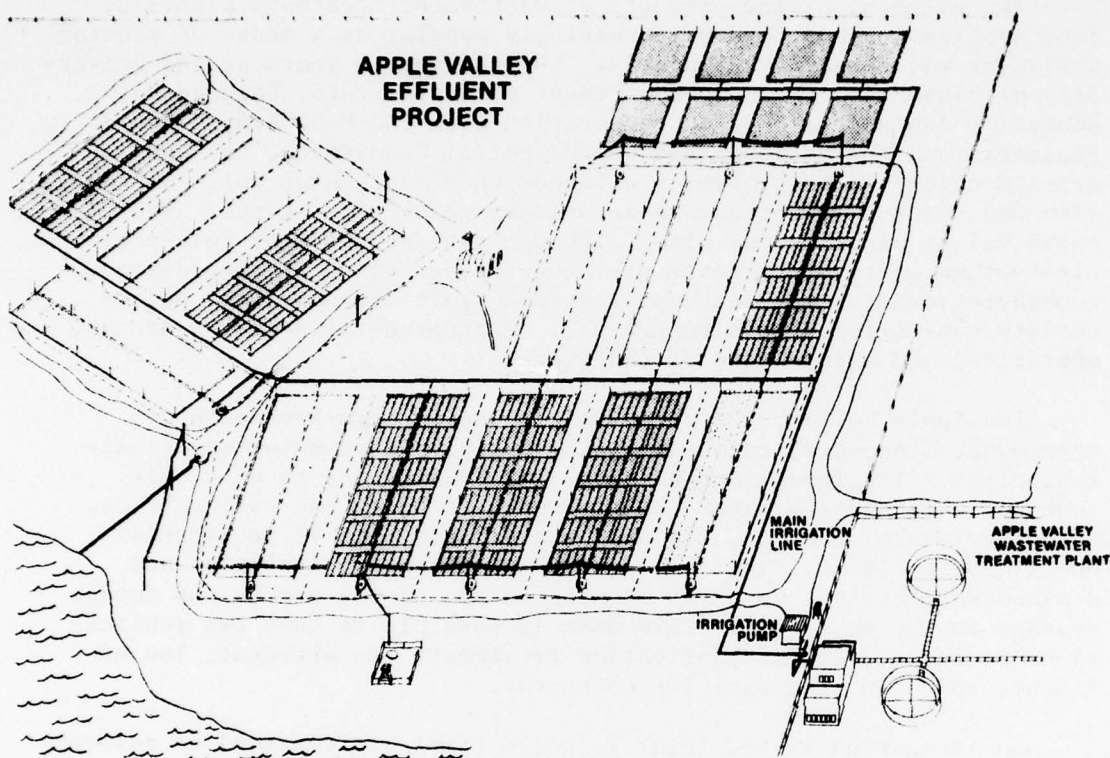


Fig. 1. Apple Valley effluent project layout.

truck and spread on farms in the area. The secondary effluent used for irrigation was pumped from the plant after sand filtration but before chlorination. The irrigation system (Fig. 1, solid line) was designed to deliver effluent or fresh water at a maximum application rate of 1 in./hr uniformly over each plot with the capability of irrigating all plots simultaneously or each plot individually. Effluent was taken out of the plant through a 5-in. steel pipe which dropped 6 ft to ground level.

Secondary effluent was chlorinated on the suction side of the pump by injecting a solution of 10% sodium hypochlorite. The solution was metered using a diaphragm pump. The pump was calibrated by testing effluent at the sprinkler heads with Toliver Solution and adjusting the pump to give a 1-ppm residual chlorine reading. The calibration chart is shown in Fig. 2.

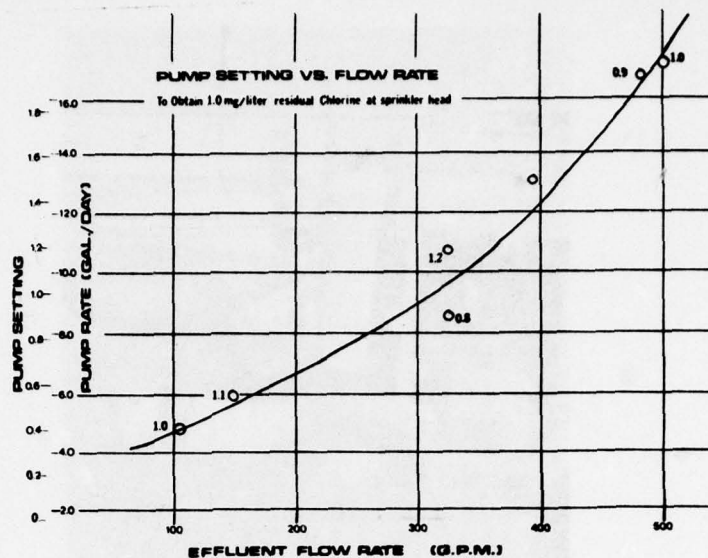


Fig. 2. Pump setting to attain 1-ppm residual chlorine.

A 5- x 4-in. centrifugal pump (Fig. 3) converted directly to a 6-cyl, 75-hp gas engine was used (Fig. 4). The unit is equipped with an intake manifold vacuum primer. The pump was rated at 400 to 1000 gpm, but it was possible to attain flow rates down to 100 gpm when effluent was being applied to only one or two plots. Pumping pressure was maintained at 50 psi.

A main 6-in. aluminum irrigation line was used above ground from the pump to each 60- x 150-ft plot. This line was coupled in 30-ft sections and could be disconnected easily. A smaller 4-in. irrigation line was used from the "T" on the main line to the 40- x 40-ft plots. Two manual 4-in. gate valves at the "T" were used to control flow in the mains.

Each individual plot was set up as in Fig. 5 with a 2-in. gate valve off the main line, a turbine-type integrating flowmeter (Fig. 5), three 3-in. laterals, and 18 risers. Four-foot risers were used on all forage plots and six-foot risers on the corn plots. Nelson type P20B sprinkler heads which could be set for full or part circle were used. The nozzle sizes and design flow rates given in Table I were designed to give uniform distribution and overall operating rates of 0.68 and 0.55 in./hr for forage and corn, respectively.

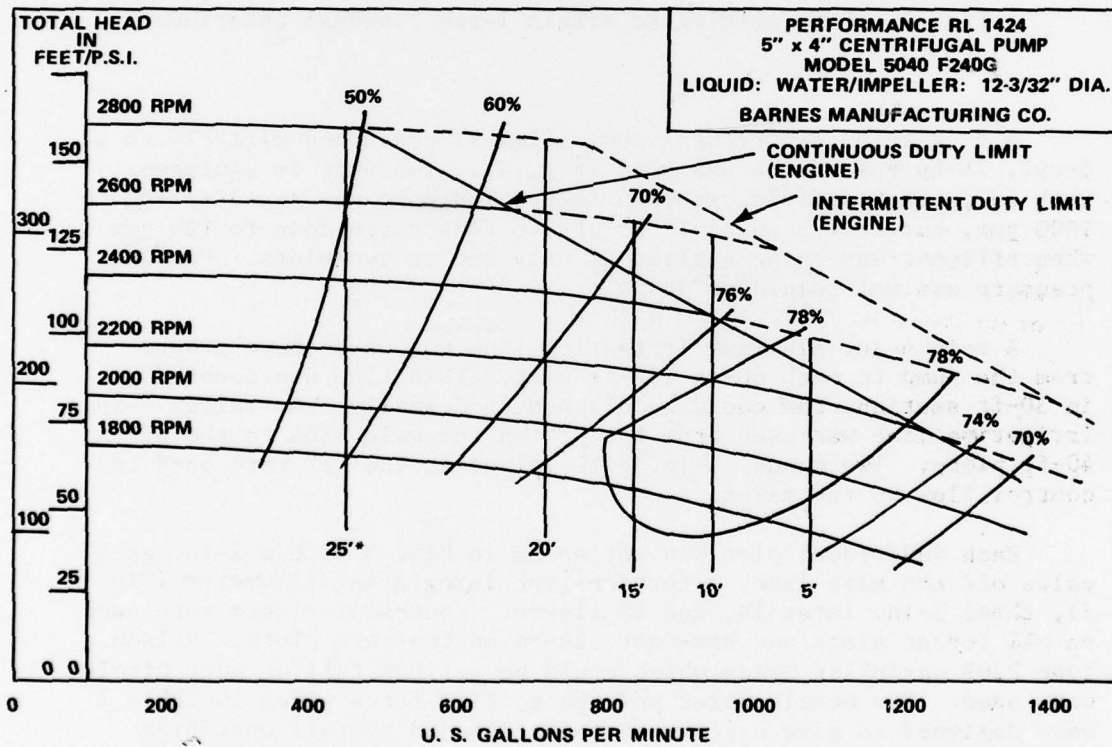
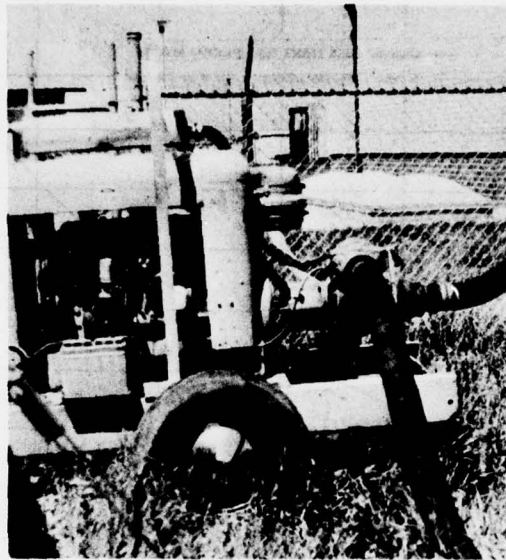
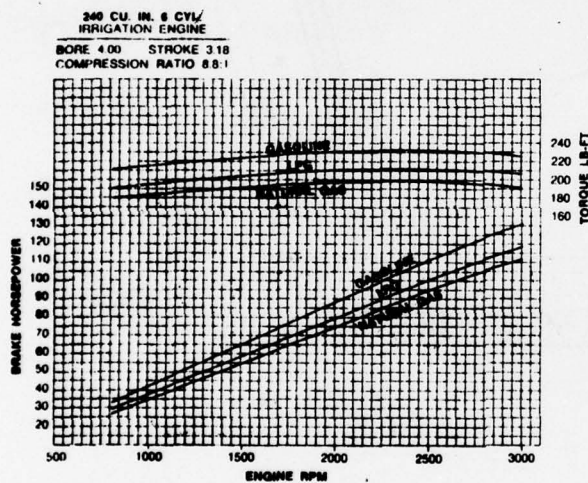


Fig. 3. Irrigation pump.

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240 CID SIX

Type inline, 6-cylinder, overhead valve
Bore and stroke 4.00 x 3.18
Displacement 240 cu. in.
Cylinders and crankcase cast iron, cast integral
Cylinder wall finish controlled quality finish for uniform oil film
Pistons aluminum alloy, autothermic type, solid skirt, tin plated
Piston rings chrome plate top compression ring—phosphate-coated second compression ring—chrome plate steel rail oil control ring with expander
Crankshaft precision-molded alloy cast iron, 7-bearing
Main and connecting rod bearings replaceable steel backed, plated copper-lead alloy
Camshaft 4-bearing, precision-molded, special alloy iron, induction-hardened
Valves—exhaust 214N steel (aluminum-coated)
—intake SAE 1047 steel (aluminum-coated)
Valve rotation—exhaust positive rotocoil type
—intake Ford free turn rotators
Exhaust valve seat inserts and hard faced exhaust valves optional
Lubrication full pressure to all bearings—full-flow filter—rotor-type oil pump
Oil capacity 6 qt dry—5 qt refill
Engine weight dry (approx.) 534 lb. (fan to flywheel)
Covered under factory warranty yes

Fig. 4. Irrigation engine and power curves.

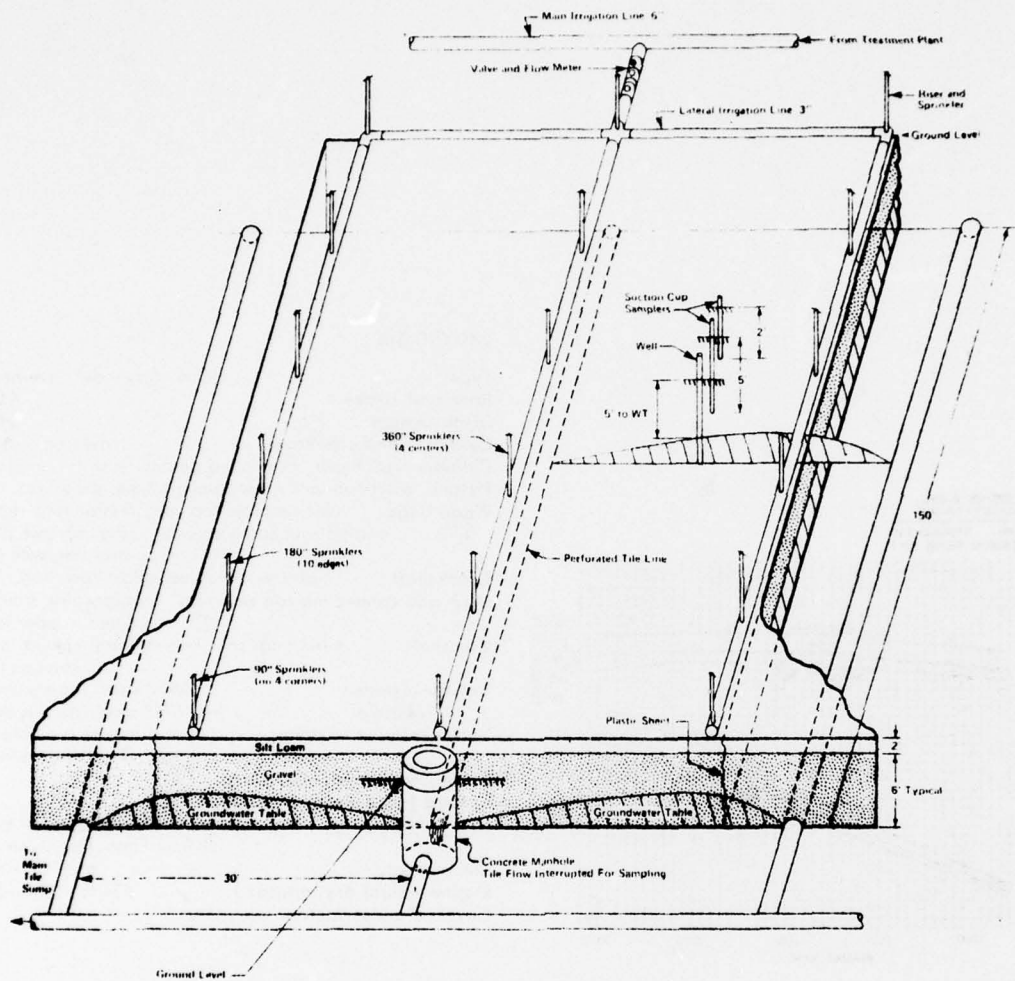


Fig. 5. Typical block layout.

Table I. Nozzle sizes and flow rates

<u>Rotation</u>	<u>No/Plot</u>	<u>Size</u>	<u>gpm/Nozzle</u>	<u>Total gpm</u>
Forage				
90	4	3/32	1.8	7.2
180	10	1/8	3.2	32.
360	4	11/64	6.0	24.
Total				63.2 gpm or 0.68 in./hr
Corn				
90	4	3/32	1.8	7.2
180	10	7/64	2.4	24.
360	4	5/32	5.0	20.
Total				51.2 gpm or 0.55 in./hr

B. Drainage system

The drainage system was designed to both hold the water table at a fixed depth below the soil surface and sample the water which entered the water table from the soil above. Before the tile drains were installed, the water table elevation was measured and found to be fairly constant at 94.5 ft (relative to a 100.0-ft bench mark at about the soil surface) or about 5 ft below the soil surface.

The tile drainage system is shown in Fig. 6 (dotted line). One 4-in. perforated tile was installed in the center of each block ending in a 4-ft concrete manhole at one end of each block. A 10-ft section of closed PVC pipe was used before the tile entered the concrete manhole at one end of each block. The tile started at an elevation of 94.0 ft (0.5 ft below the design 94.5-ft water table) and sloped to 93.55 ft at the well. The flow was then allowed to drop 1 ft in the well before flowing into the 6-in. main solid tile sloped 0.003 ft/ft to a common 6-ft concrete sump. In addition to the tile down the center of each block, a 4-in. perforated tile was positioned between each block and on the outside edge of the corner blocks. These were also connected to the main tile and ran to the sump. Thus, the distance between tiles was 45 ft. Normally with a soil as permeable as at Apple Valley (essentially a gravel base below 5 ft) tiles would be set 100 to 200 ft apart.

A sump pump (Fig. 7) powered by a 3-hp electric motor was used to lift water to a nearby stream. This was controlled by a high-low electronic level shutoff. A 6-ft-wide polyethylene sheet was

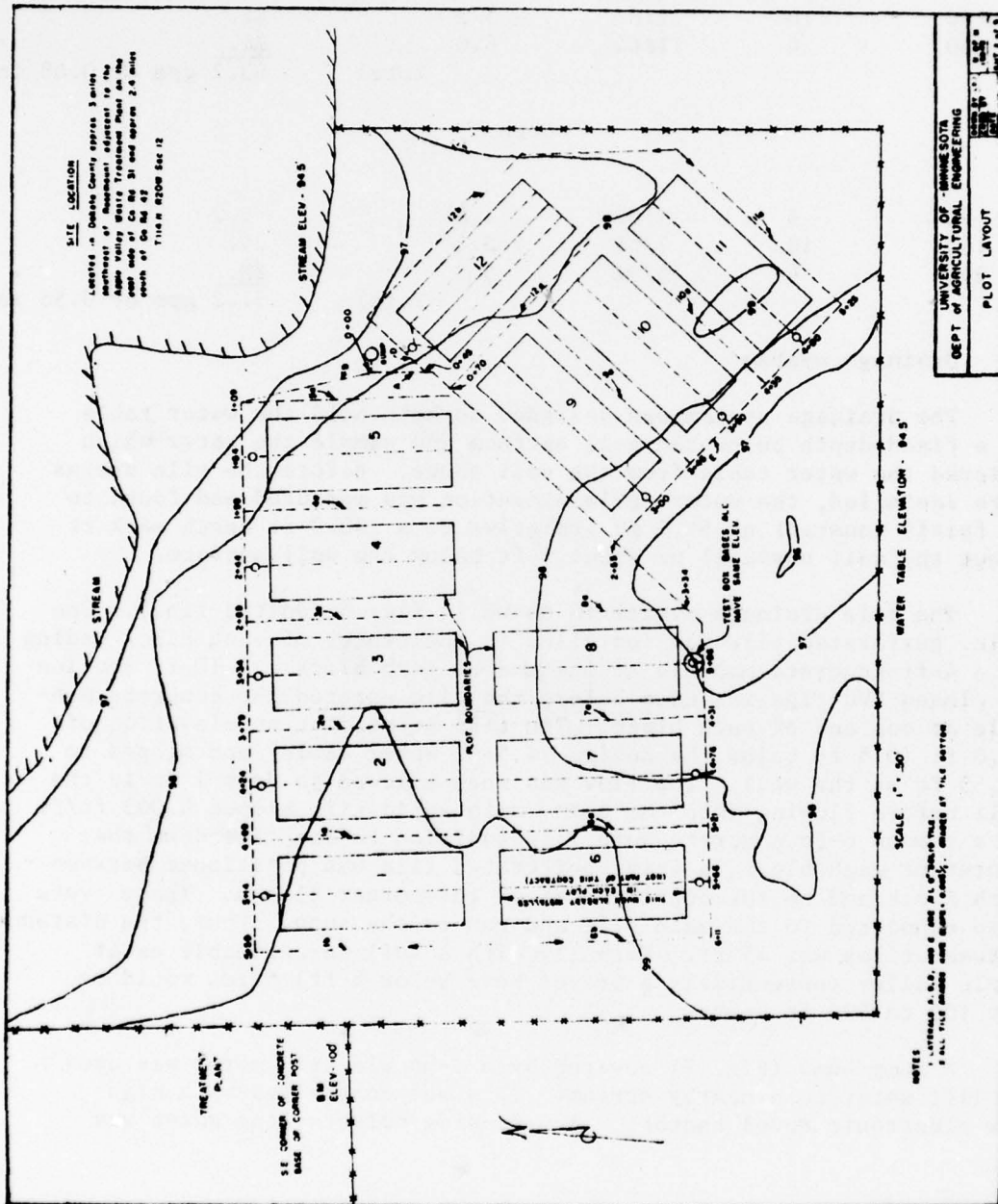


Fig 6. Tile drainage system.

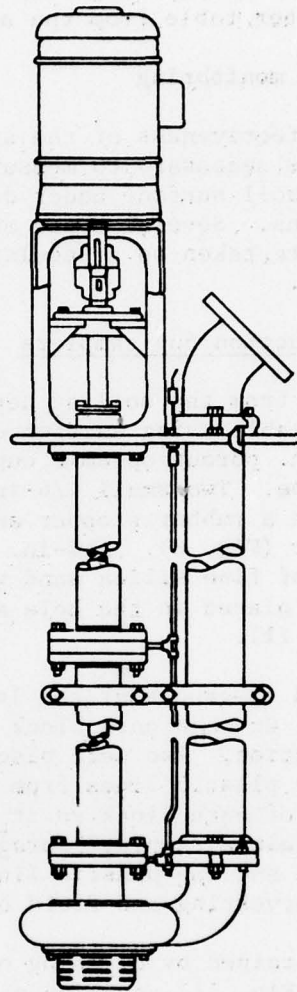


Fig. 7. Clow sump pump.

buried along the edge of each block to prevent cross flow. Therefore, it was hoped that a groundwater profile as in Fig. 5 (an exaggerated slope) would allow a qualitative and perhaps quantitative measurement of water entering the water table from the soil above.

C. Instrumentation and monitoring

To determine the effectiveness of the system for renovating secondary effluent it was necessary to measure the water quality at various depths from the soil surface under different cropping and soil management conditions. Several types of water sampling methods were used and samples were taken on a regular basis and analyzed chemically in the laboratory.

Porous ceramic or suction cup samplers

Water was extracted from the soil at depths from near the surface to just above the water table using suction cup samplers (see Fig. 8). These consisted of a 2-in. porous ceramic cup glued to a 2-ft length of 2-in.-diameter PVC pipe. Two small 1/4-in. flexible polyethylene tubes were pulled through a rubber stopper and the stopper inserted in the end of the sampler (Fig. 8). A 4-in. hole was augered to the desired depth, a slurry of fine silica sand was poured into the hole, and the sampler assembly placed in the hole and backfilled to the soil surface (Fig. 9, 10, and 11).

Samplers were placed in groups at the locations indicated by a vertical bar in Fig. 12. On each corn block four suction samplers were grouped at each location. Two were placed at a 2-ft depth and two at a 5-ft depth. The plastic lines from each sampler were run above ground to the edge of each block so it was not necessary to walk into the corn to obtain a sample. Forage blocks had only two samplers at each location and the plastic lines were buried just below the turf to facilitate harvesting and field operations.

A sample was then obtained by clamping one of the flexible tubes, called the air line (see Fig. 11), pumping a vacuum on the system for 2 to 3 hrs, and releasing the clamp on the air line to collect a sample in the side arm flask (Fig. 13).

To facilitate collection of samples from 160 individual ceramic cups, a central vacuum system with 1 pump and 5 vacuum storage tanks was used (Fig. 14). A valve at each vacuum storage tank controlled samplers in one area, so it was possible to shut off one area to isolate leaks. A control system (Fig. 15) would turn the vacuum pump on when necessary to hold the vacuum at 400 mm of mercury.

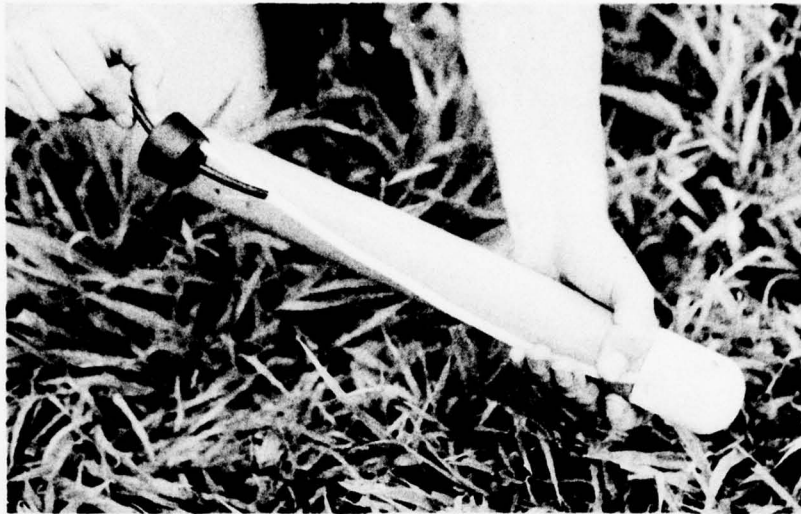


Fig. 8. Suction cup sampler.

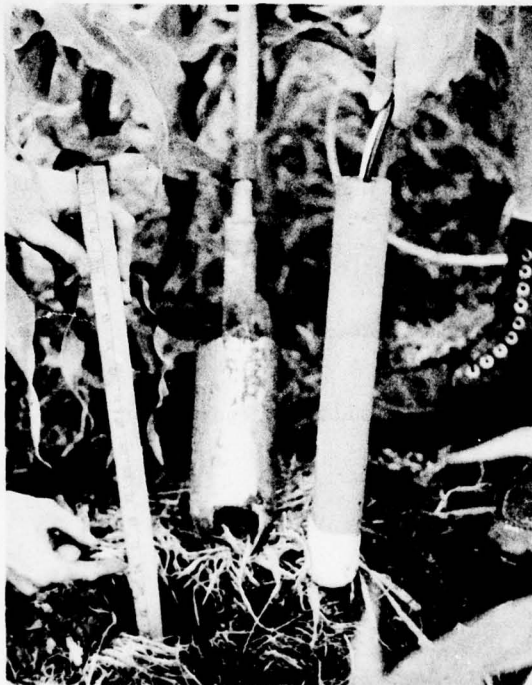


Fig. 9. Augering hole.



Fig. 10. Pouring a silica flour slurry in the hole.

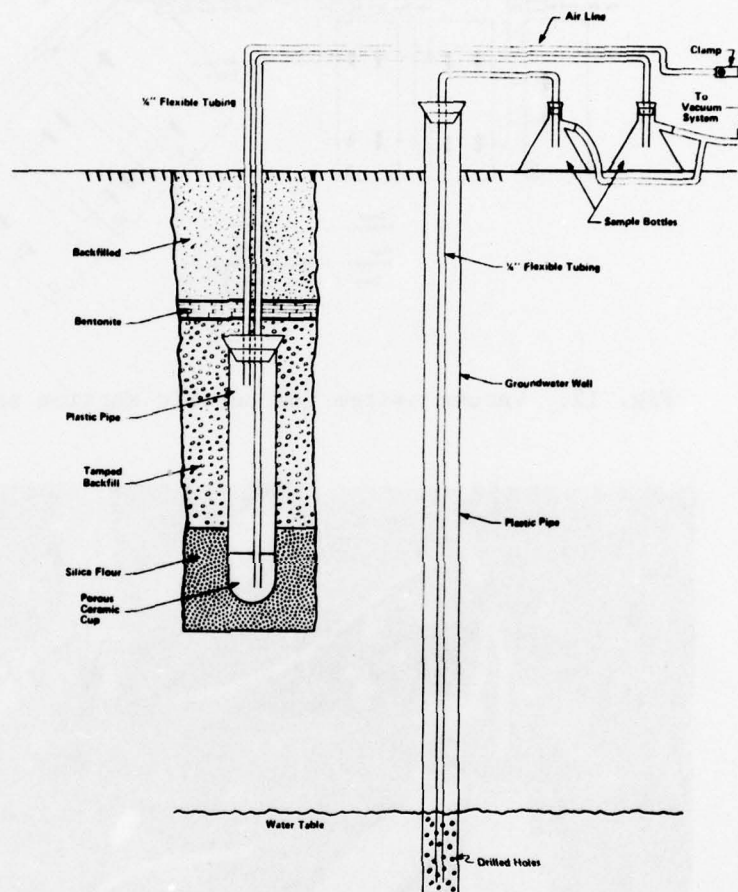


Fig. 11. Suction cup sampler and groundwater well.

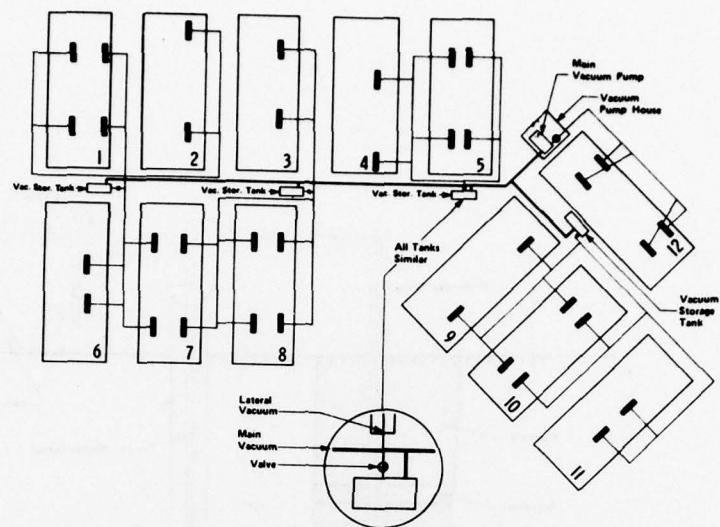


Fig. 12. Vacuum system for ceramic suction samplers.



Fig. 13. Sample bottles connected to vacuum system.

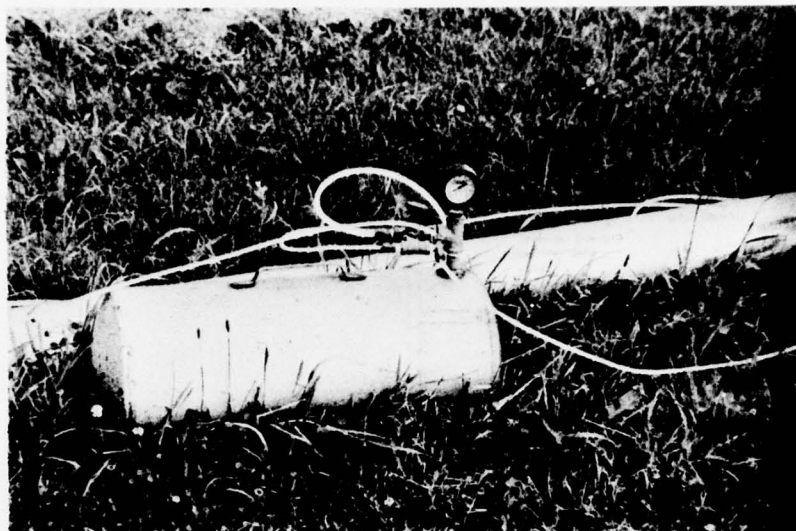


Fig. 14. Vacuum storage tanks.

Groundwater wells

Ordinary 2-in.-diameter PVC pipe was used for wells as a means of extracting samples from the water table (Fig. 11). Since the water table was only about 6 ft below the soil surface, wells could be drilled using a hand auger. A 1/4-in. flexible polyethylene tube was inserted in the well and samples were collected using the same vacuum system (see Fig. 15) as for the porous ceramic samplers.

Tile water

Water flowing from the center tile drain of each block was carefully monitored by measuring the flow rate and sampling the water at intervals.

The flow rate was measured using a water stage recorder and slotted tube. The method as shown in Fig. 16 consists of a 1/2-in. I.D. slotted tube placed perpendicular to the flow stream at the tile outlet¹. This tube is connected to a 6-in. I.D. stilling well

¹Larsen, C. L. and L. F. Hersmeier. Device for measuring pipe effluent. *Agricultural Engineers* 1958, vol. 39, no. 5, pp. 282-284, 287.

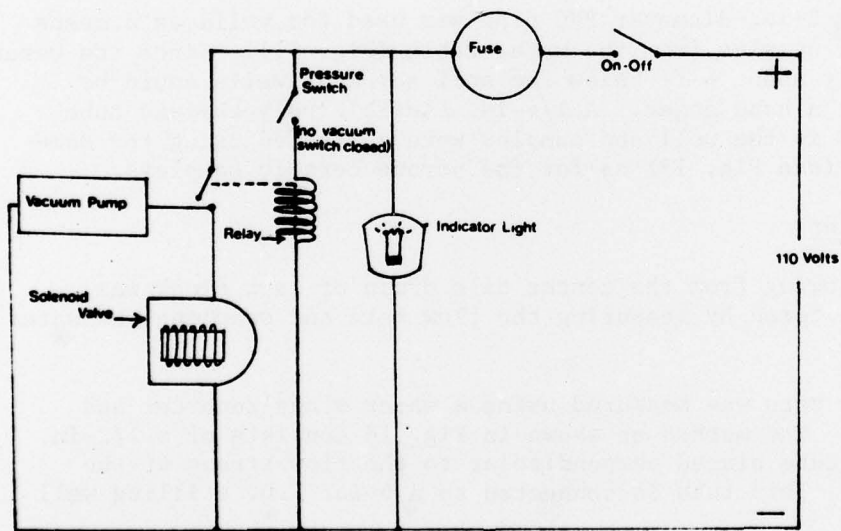
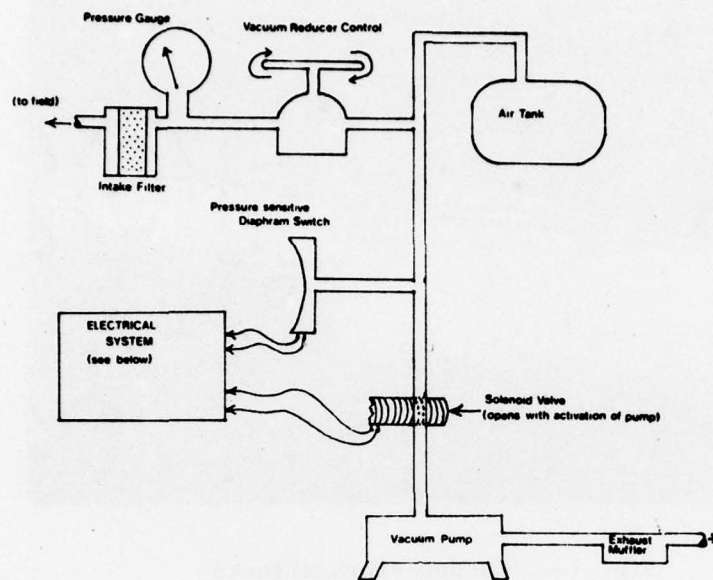


Fig. 15. Vacuum control system and electrical schematic.

where water level is the same height as the water flow out the tile. A float connected to a perforated steel tape translates water level changes to a recorder (Fig. 17) which will operate for one week without a chart change. Water level changes of .01 ft were recorded accurately.

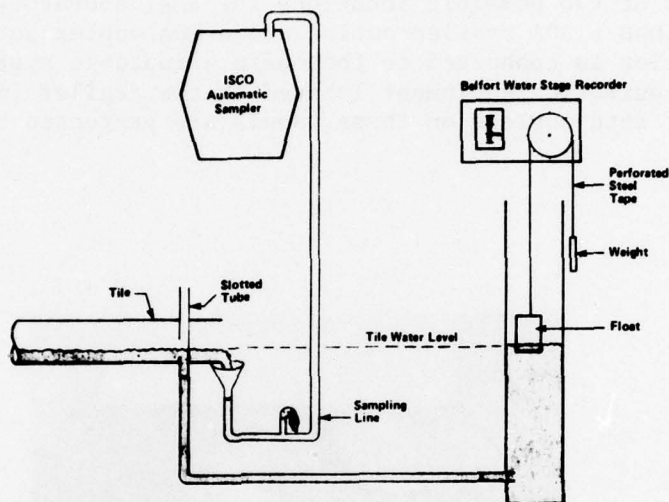


Fig. 16. Tile water sampling and flow recording system.

Water samples were taken periodically using an automatic sampler. The instrument (Fig. 18) could be set to take a sample at intervals of 1 to 12 hrs and also composite samples up to 4 per container with 28 containers available in the unit.

Electrical system

The electrical system (Fig. 19) is an overhead system with power panels adjacent to each test plot sampling station.

The overall system consists of essentially two separate systems. One system has an automatic transfer switch which switches to a standby generator in case of a power outage in the supply line. This supplies noninterruptable power for the sampling and data collecting equipment and the sump pump.

The other system is dead when there may be a break in the power line.

Power panels

A power panel (Fig. 20) at each sampling station is equipped with two duplex outlets, each of which has a ground fault interrupter (GFI) and is fused to 20 A. One duplex outlet on the noninterruptable circuit provides power for the water quality samplers. The other outlet is on the interruptable circuit and provides power for miscellaneous service equipment, like heat lamps and power tools.

A second power panel design (Fig. 20) is located at the weather station and at two possible locations for the laboratory trailer. This panel has a 30A trailer outlet and a 20A duplex outlet. The trailer outlet is connected to the noninterruptable system to keep any data acquisition equipment located in the trailer in continuous operation. Both outlets on these panels are protected by GFI.

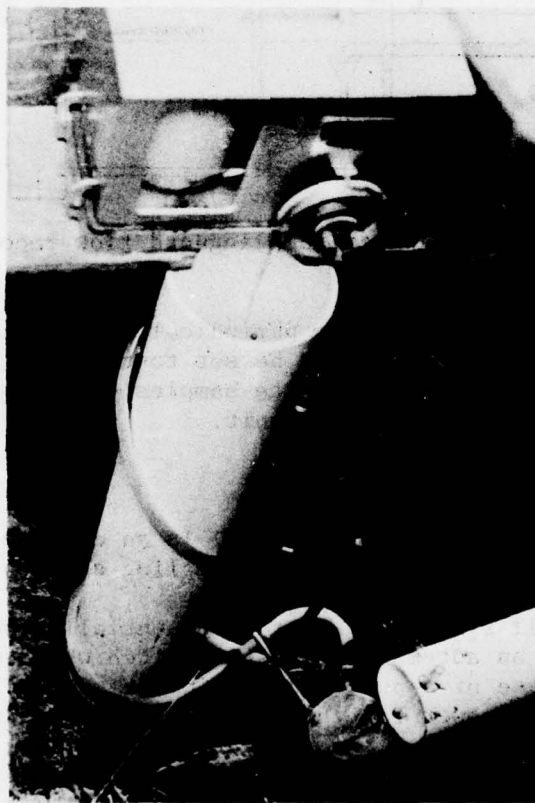


Fig. 17. Belfort water stage recorder.

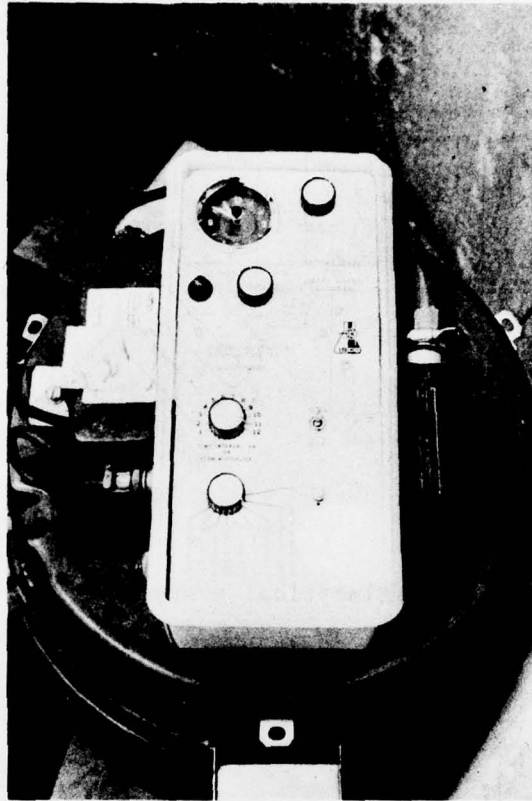


Fig. 18. ISCO automatic sampler.

A third distribution panel (Fig. 21) provides 3-phase power to the drainage sump pump and is on the noninterruptable system.

All distribution panels are rain tight and grounded to the water table with copper ground rod. The panels are mounted on the line poles 6 ft from the ground. The drop power wires enter a conduit through rain tight weather head near the top of the pole and are conducted by the conduit down to the distribution panels.

The overhead lines are outside the plot boundaries so they do not interfere with the spray irrigation system. The automatic transfer switch is tested weekly to check the operation of the standby power unit and the noninterruptable system.

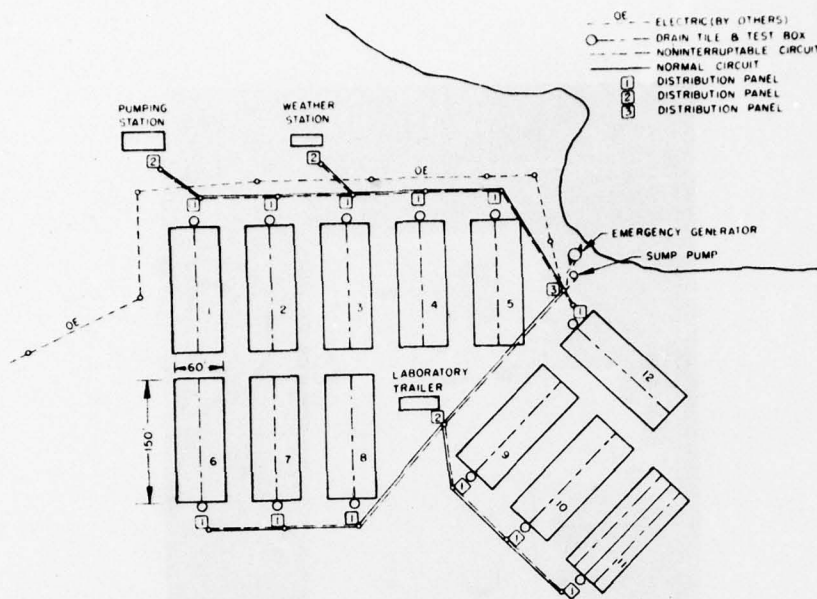


Fig. 19. Electrical system.

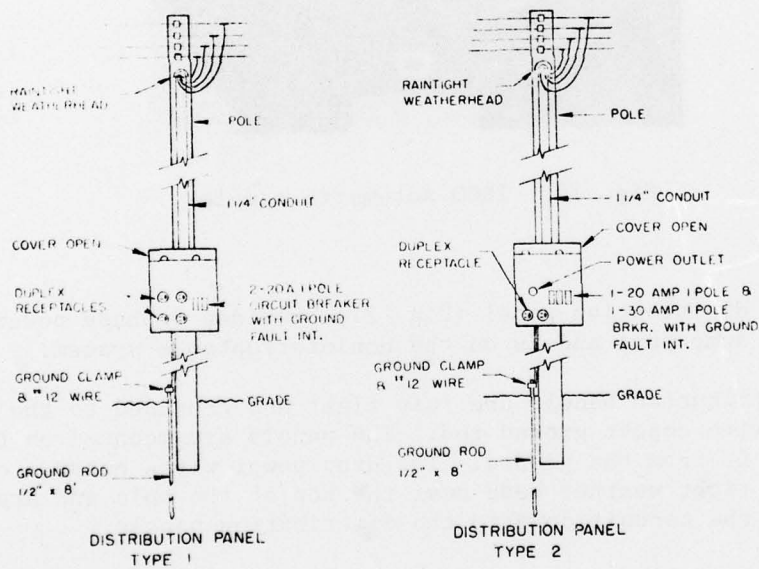


Fig. 20. Sampling station power panel.

Power use for the trials in 1976 was 10,000 kwh.

Effluent sampling

Effluent was sampled for chemical analysis by simply placing pans on each block. It was found necessary because of chemical changes between the pump and the plot to place pans on each block rather than sampling the main effluent stream directly. Effluent samples and all water samples were stored in Whirlpak polyethylene bags of 400-ml capacity. All samples were refrigerated in the field and during storage before analysis.

Weather

The weather was monitored using a standard National Weather Service Station, including Belfort recording temperature and rain gauges and 4-cup anemometer. The weather data were taken daily during the summer months. Snowfall measurements were made during winter months.

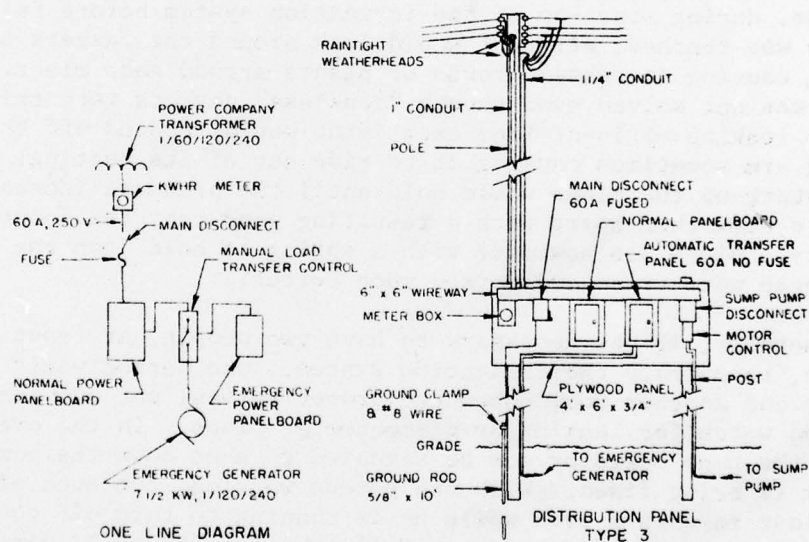


Fig. 21. Main distribution panel design.

II. Operation and maintenance

A. Irrigation system

The irrigation system itself worked well with little maintenance. The aluminum pipes could be disconnected, moved, and reassembled easily for field operations. An occasional hole or split in the aluminum pipe could be easily repaired with an ordinary fiberglass cloth and epoxy auto repair kit. Effluent was pumped from the plant after it was filtered so nozzles would seldom become clogged, and usually could be cleaned with a short wire. Most clogging occurred after the pipes had been disconnected when grass, mice, and gophers trapped inside would be forced to sprinkler heads and nozzles.

The most difficult problem inherent in all overhead irrigation systems was the inability to obtain uniform coverage when the wind was blowing. Even a slight wind would necessitate adjustment of most of the sprinkler heads. With a crosswind, for example, upwind 180° sprinklers had to be set to travel 270° so the edge of the plot would be irrigated uniformly. Similarly, downwind 180° sprinklers would be set to travel 90° to prevent effluent from being sprayed into the alleys. It was often necessary to irrigate during the calmer early evening hours, but even with this care, growth was better in the center of the plots during the 1976 season.

Also, during start-up of the irrigation system before full pressure was reached, effluent would leak around the gaskets at each coupling causing increased growth of plants around each riser. This problem was not solved even though "leakless" gaskets were tried. Also the leaking effluent from each joint would rebound off the coupling arm sometimes causing it to ride out of its seating. Then, during start-up the pipes would hold until the pressure increased enough to blow them apart with a resulting pond near the joint. Newer style pipes are now made with a spring to hold down the coupling arm. These were tried and worked much better.

Generally, it was necessary to have two people, at least during start-up, to operate the irrigation system. One person would start the pump and another would open the proper valves, set out sampling pans, and watch for leaking or disconnected pipes. In the event of a leak, the pump operator can be signaled to shut down the pump while the leak is being fixed. With one person working, too much effluent can be lost through a leak while he is running to turn off the pump. After the system was operating at full pressure (50 psi), generally no leaks occurred. Thus, for evening irrigation the system would be started at 5 p.m. when the day crew was available to help, and only one person would stay to operate and turn off the pump.

B. Irrigation pump

The gas-engine-powered irrigation pump has continued to work well over three seasons with little maintenance. The initial throttle adjustment was sufficient to hold a constant line pressure while pumping continuously for 6 hrs. The positive head on the suction side of the pump made priming easy and also made it possible to pump at low flow rates. During 1974, when effluent was taken from a sump in the treatment plant which was 10 ft below the pump, it was not possible to pump low volumes needed for irrigating only two blocks.

C. Chlorination system

Initially the system designed to accurately chlorinate the effluent used for irrigation was plagued with problems. During the first years of the experiment, effluent was pumped from the plant at a point before the filters. Thus, the solids content of the effluent varied considerably and the amount of chlorine necessary to bring the effluent to 1-ppm residual chlorine varied accordingly and was difficult to adjust. Later, it was decided to take effluent from behind the plant's sand filtering system and the variation in the solids content of the effluent decreased and chlorination was easier.

D. Gate valves and flowmeters

Two-inch-diameter brass manual gate valves were used to control flow to each block. The valves worked well, with only one problem. The configuration of the chamber in which the gate slides was such that effluent remained in the valve after the pump was shut off. Therefore, several of the valves were broken each season by ice during early frosts. It is possible to obtain self-draining valves, these are recommended.

Two types of flowmeters were used. The 12 flowmeters used on the main plots were heavy brass with metal gearing and counters. These worked quite well, were chemically resistant, and stalled only occasionally due to debris caught in the turbine blades. Eight meters used on an additional experiment had plastic meter inserts with plastic gearing and counters. These lasted only a season before the gearing would periodically bind, causing the turbine to stall and the counter to give false flow measurements.

E. Drainage system

The tile system was operated continuously (except for a few of the coldest weeks) 12 months a year. Even during winter months, the electric sump pump would cycle and the tiles of most blocks would flow and could be sampled. The sump pump itself has run continuously

for 3 years with no maintenance, and, except for one faulty transistor and an occasional cleaning of sensing rods, the control unit has had no maintenance.

One difficulty encountered with the drainage system has been due to the fluctuating water table. The water table is highest in the spring and lowest in late summer. It also fluctuates 0.5 ft across the plot area. During the spring for several weeks, the main drain line connecting the lateral lines is not large enough to handle the increased flow and thus the laterals would back up, flood the wells, and no flowing water samples could be taken. Later in the summer, the water table would drop below several of the tiles and thus they would stop flowing. We initially thought that the large amounts of effluent sprinkled on the blocks would compensate for the seasonal drop in the water table level. However, when the water table in the whole valley would drop, the water table under the plots would drop. Therefore, it was impossible to obtain quantitative water quality measurements of tile water. In fact, nutrient concentration data from the tiles were questionable, since tiles deeper in the water table could be diluted by existing groundwater. No simple method, except using a lysimeter for each plot, was devised to solve this problem, so tile water flow and water quality data were de-emphasized in favor of suction cup data.

Also, the tile of Block 5, which was nearest the effluent stream, continuously gave high concentrations near the stream. However, when individual wells closer to the stream than Block 5 were installed and monitored, no abnormally high concentrations of nutrients in the groundwater were found. This problem needs further investigation.

F. Instrumentation and monitoring--Suction cup samplers

One method of extracting moisture from soil without removing the soil or disturbing the surrounding area is with porous ceramic suction cup samplers. It is necessary to initially auger a hole for the cup, but once it is installed, it can be left in the ground for years while samples are taken periodically. The suction cups, however, only sample soil water within a few inches of the cup, so several cups were installed on each block to give a more representative sampling. On each corn block, there were a total of 16 suction cups in groups of 4 at 4 locations. At each location, two cups were installed 2 ft below the soil surface and two cups at 5 ft. One of the difficulties on the corn blocks was that at each of the four cup locations it was impossible to plow, disc, or plant without disturbing the cups. Even though the cups were buried, the plow would have to rise over the locations so as not to cut the plastic tubing running from the cups. It was then necessary to till and plant the

area by hand and thus not exactly representative of the block treatment. If we were to install cups again, we would use a trencher to bury both the cups and plastic lines 1-1/2 ft below the soil surface. This would simplify field operations considerably and give more representative results.

Initially, 3/4-in.-diameter suction cups were used, and even though a vacuum was placed on the cups for several hours, it was sometimes difficult to obtain a large enough sample volume for analysis. This was particularly true on the control plots which were generally drier. The cups presently used are 2-in. diameter and worked much better. Sample volumes of 100-500 ml were average after 3 hours of vacuum.

Normally it would take 2 people 8 hours to collect all the samples from 160 suction cups. The vacuum would be turned on in the morning and after 2 hours samples could be taken. These were generally collected in sterilized 400-ml "Whirlpak" polyethylene bags and refrigerated until analysis could be made.

Isolation of leaks in the vacuum system was a continual problem. It was almost normal procedure to find all the leaks each week before samples could be taken. To save polyethylene tubing, vacuum lines were connected using plastic "T's." These were a constant source of leakage. Several types were tried and most would work for a period, but eventually they would loosen and leak. In some cases "T's" were used to save 30 ft of tubing, which was probably not wise. Each year about 20% of the samples were lost due to winter freezing. Generally, when leaks were traced to the buried sampler itself, it was discarded and left in the ground.

Groundwater wells

The groundwater wells, installed at the same location as the suction cup samplers, caused similar problems for field management. Since water table elevation measurements were required, it was necessary to have access to the wells and thus they protruded a few inches above the soil surface. Without the necessity of water table measurements, it would have been possible to terminate and cap the wells 2 ft below the soil surface and remove well samples through buried tubing.

Tile monitoring

The instrumentation used to monitor the tile drainage system worked quite well. Except for occasional electronic problems, the ISCO automatic samplers were reliable. The samplers initially operated using 12-v. auto batteries and presently run off 100-v. AC power.

The Belfort flow recorders used to monitor tile flow were accurate to ± 0.01 ft (0.12 in.) Charts were used that would run for a week without changing. During 1975, the flow recorders were set up to read automatically with a geared potentiometer attached to the float wheel. Then 5-v. DC power was applied to the potentiometer and a calibrated voltage was determined for each flow rate. The voltage was monitored at one central point in a trailer house using a VIDAR data logging system. The recorders worked extremely well, but the data logging system was difficult to program and subject to electronic breakdown during electrical storms. Isolation transformers were used to solve this problem, but without success. After inherent difficulties with water table fluctuations as indicated previously, the interest in a quantitative measurement of tile discharge was abandoned and accurate tile flow measurement was not necessary. Therefore, the flow recorders were again set up with charts and the data logging system was not used.